



Sinkholes along the Dead Sea Coast and their Development

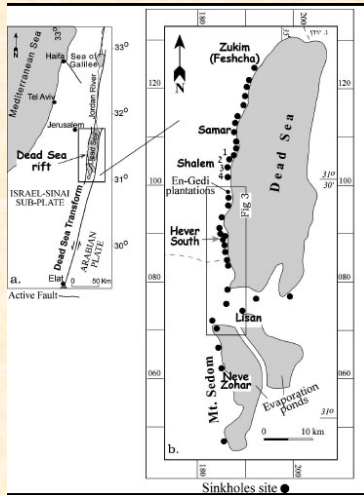
Boris SHIRMAN and Michael RYBAKOV



Over the past several years, the coastal area around the declining Dead Sea has undergone a catastrophic collapse. One of the major expressions of this process is the sudden appearance of hundreds of collapse sinkholes, causing a severe threat to the future of this region.

We shall touch briefly on the sinkhole phenomenon and center our attention on micromagnetic techniques in which the authors were involved.

The Phenomenon



Sinkholes

Location: Dead Sea coastlines in Israel and Jordan within a narrow strip of 60 km long and about 1 km wide

Concentration: in clusters, parallel to the general direction of the Dead Sea fault system

Period: started appearing in the early 1980s

Development: since 2000 accelerated, with a rate of 150-300 per year

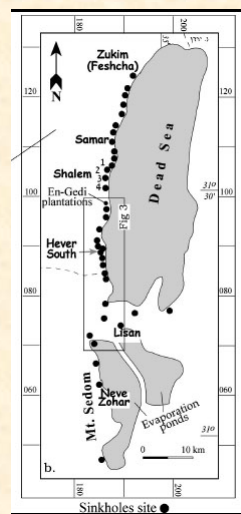
Total today: more than 1,700

Shape: well (gravel holes) or crater (mud holes)

Size: can reach a diameter of more than 30 m and a depth of 20 m

Occurrence: collapse of upper ground layer

Sinkholes in the pictures



a (Shalem)

b (Samar)

c (Hever)

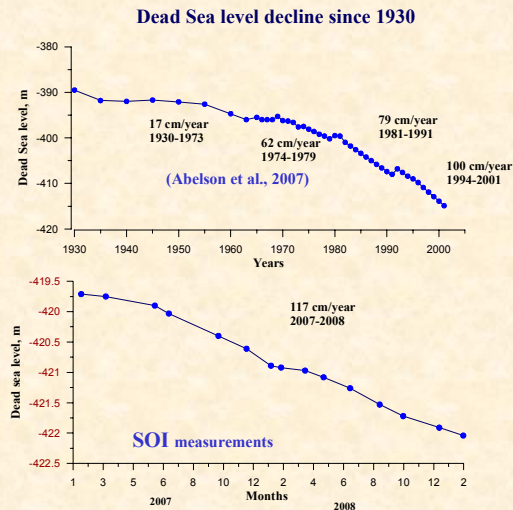
d,e (En-Gedi)

Sinkholes were going on:

- a,b in mud-flats
- c,d,e in alluvial fan

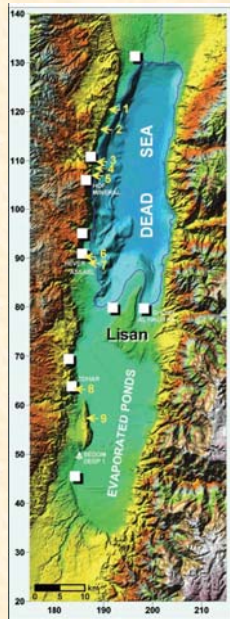
(Yeichieli et al, 2005)

The formation of these sinkholes is connected to the dramatic drop of the Dead Sea water level and associated groundwater levels.



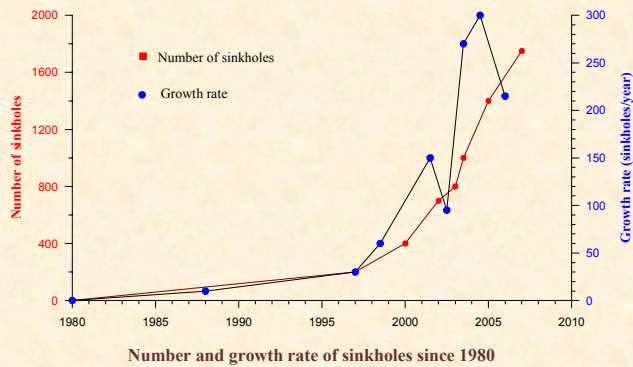
The contributing factor for this decline in succeeding years was the interception of the freshwater flow to the Dead Sea upstream by agricultural, industrial and other needs of surrounding countries.

Location of sinkholes (white squares)



Dead Sea level decline and sinkholes number changes

The sinkholes have evolved due to the dramatic decline of the Dead Sea level, which exceed 30 m since the early 1930's



GIS data processing:

The sinkhole development significantly accelerated since 1997; currently there are more than 1700 sinkholes and their number increases by a rate of 200-300 per year. (Abelson et al, 2007)

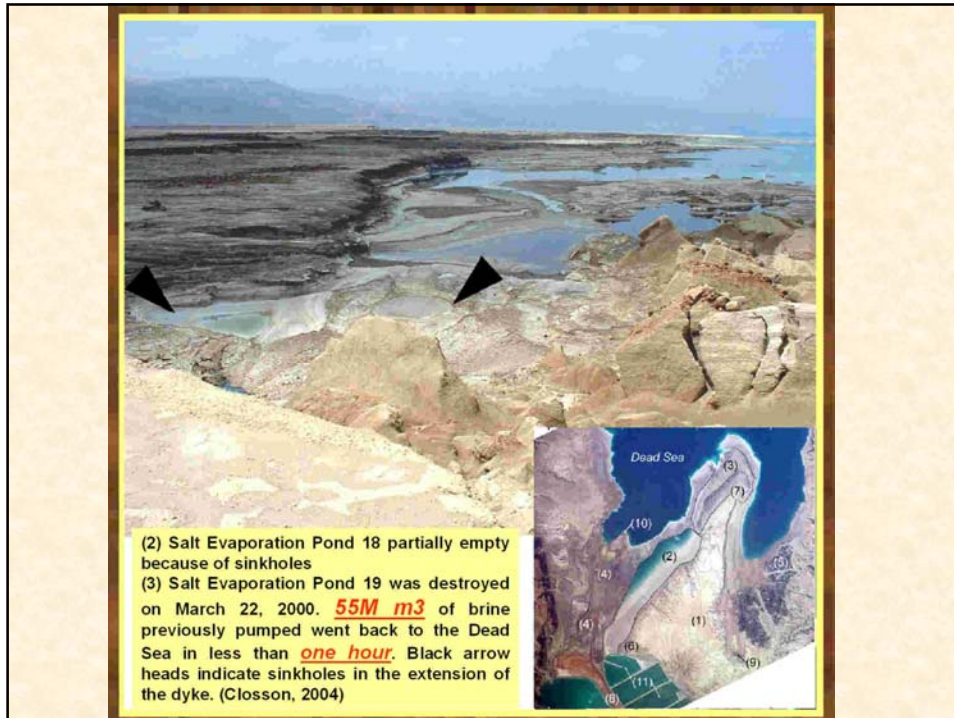
Hazard

Collapse-sinkholes are an environmental hazard. An alarming case occurred recently in the resort area, on Highway 90, and at the Israeli and Jordanian potash plants.



Sinkhole in the E'n Gedi camp (after Gilat, 1999).





METHODS TO INVESTIGATE AND PREDICT SINKHOLES

Geodesy

Aerial photography

InSAR (Interferometer Synthetic Aperture Radar)

Geophysics

Seismic refraction

Geoelectric survey

Microgravity

Micromagnetics

Boreholes

Hydrogeology

Geology

The Geological Survey of Israel and Geophysical Institute of Israel employed a variety of tools such as seismic reflection and refraction, electrical methods, drilling and groundwater sampling.

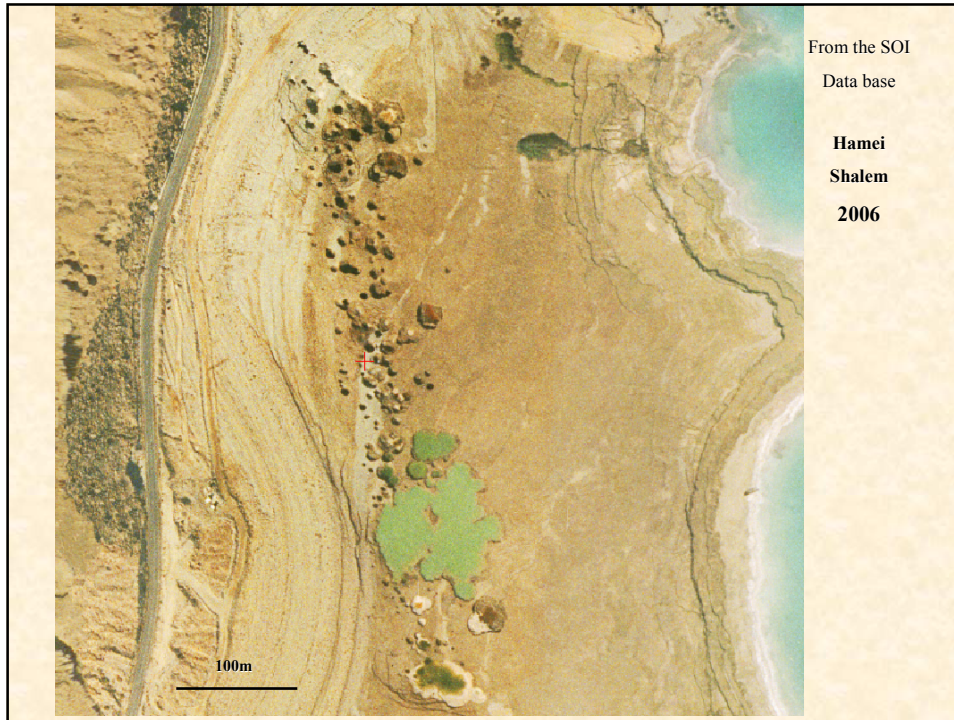
Also, the Survey of Israel made a contribution to sinkhole investigation in aerial photograph interpretation, micromagnetic techniques development and following the Dead Sea level decrease in recent years.

**Aerial photograph
Hamei Shalem site**

Mapping was carried out using ortho-rectified aerial photographs from the archive of the Survey of Israel from: 1990, 1992, 1993, 1995 and 1997. It was shown (Itamar and Raizman, 2000), that sinkholes are not distributed randomly but concentrated in clusters along the Dead Sea shore.
Scale: from 1:1000 to 1:40000
(GSI-Report \22(2000)

Hamei Shalem

Sinkholes grew in number and in size in 1999 compared with 1995



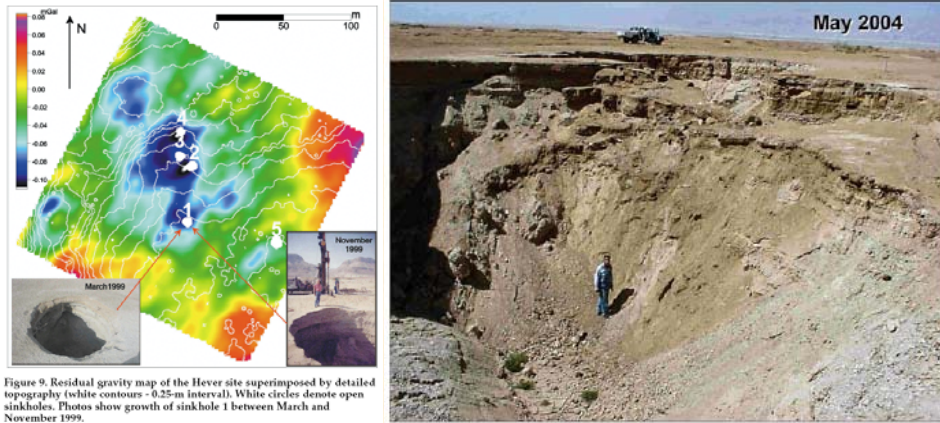
Ortho-rectified aerial photographs
Hamei Shalem 2003-2008

Green spots in the pictures are defined as sinkholes filled by water:
2003 – some isolated spots; 2006 – the central spots merged together; 2008- a merged spot expanded to the North.



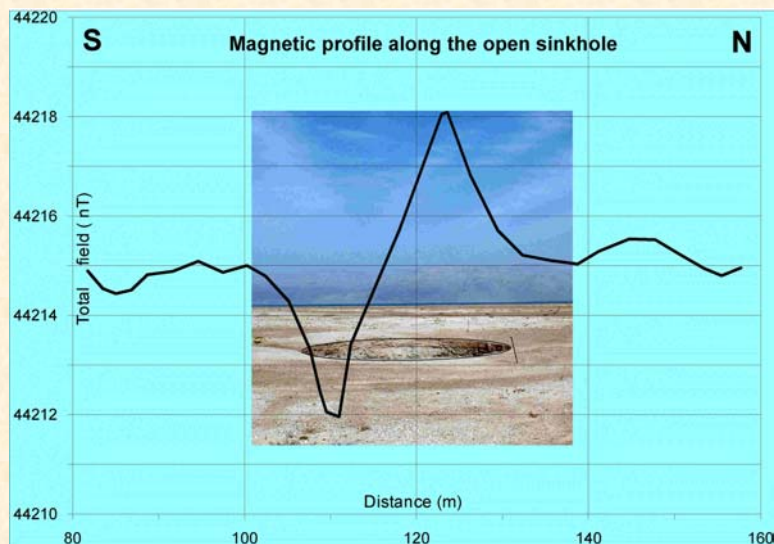
Gravimetry

The method is based on the assumption that density in a sinkhole area is lower than in the surrounding area



The gravimeter with resolution of 0.005 mGal can detect a void of 8 m in size filled by salt water at a depth of 16 m or filled by air at a depth of 24 m. (Rybakov et. All., 2001)

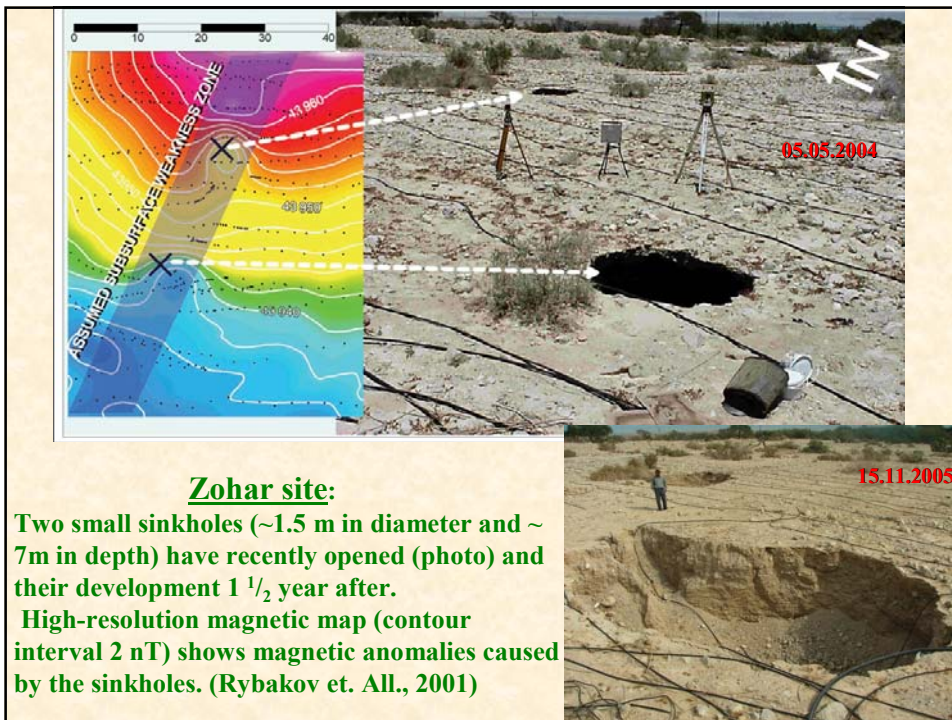
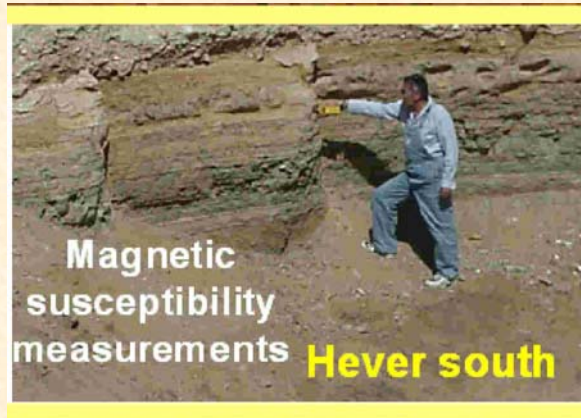
Magnetometry



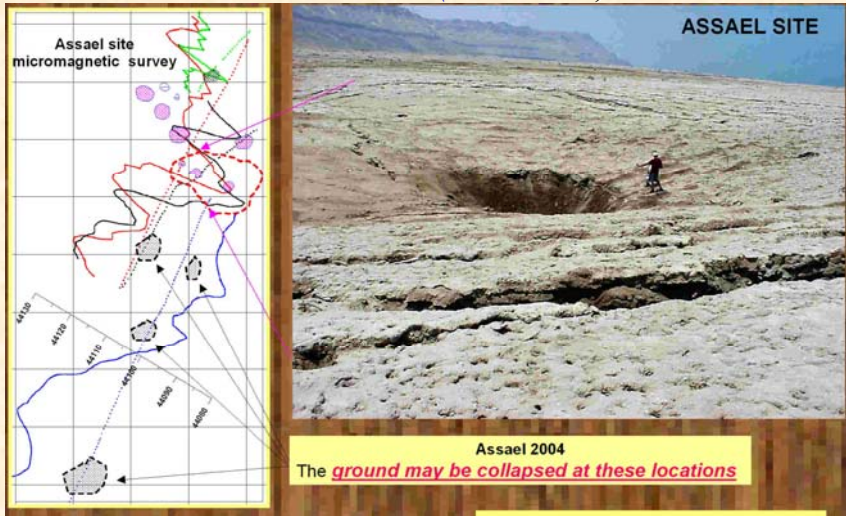
The technique is based on revealing negative anomalies using magnetic mapping at a bounded region. Modeling shows that susceptibility of sediments of 14-16 micro sgs allows us to detect hollowness at a depth of about 10-15 m.

The magnetic measurements

(field equipment)

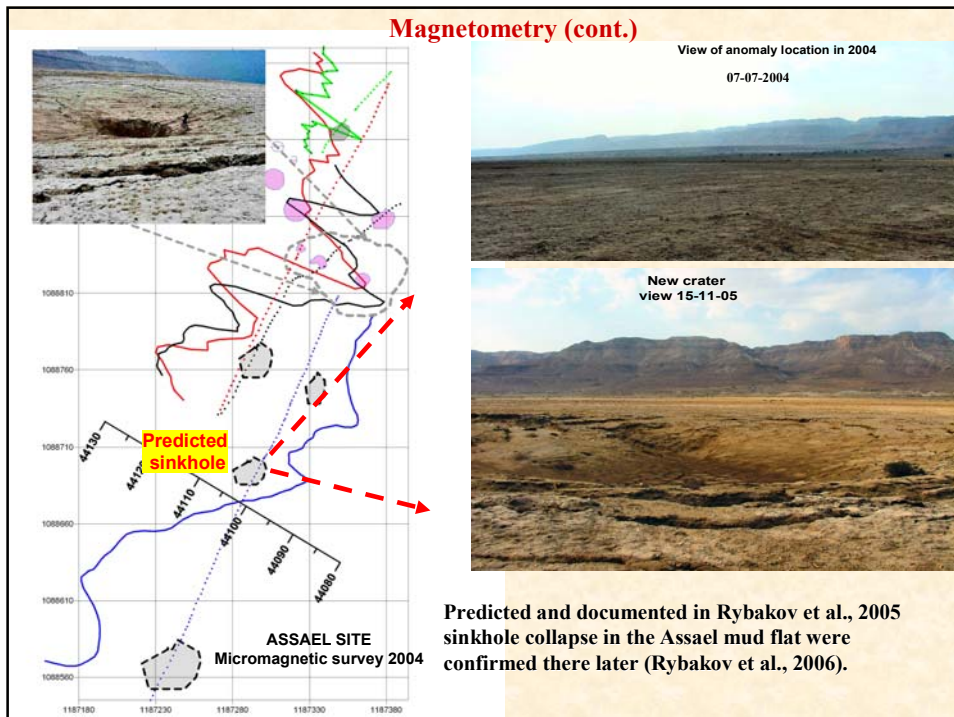


Assael site (mud flat)



Magnetic anomalies located out of the sinkhole cluster suggest a subsurface mass deficiency which will cause future ground collapse. Such locations are shown by gray polygons bounded by dashed black lines. (Rybakov et. All., 2001)

Magnetometry (cont.)

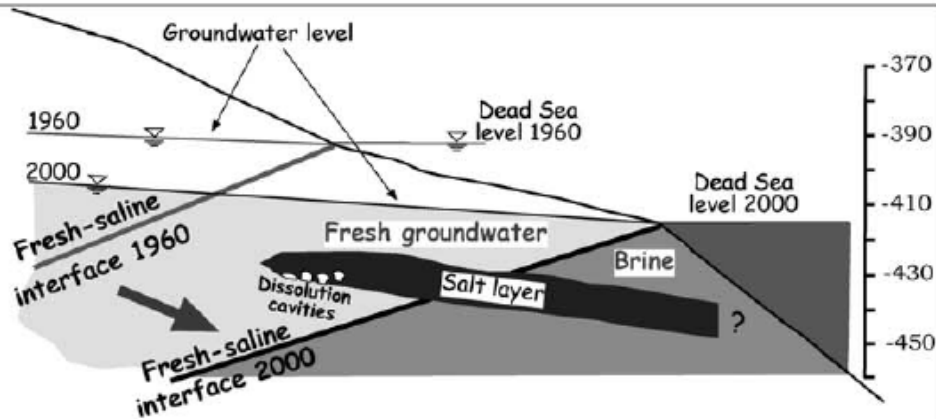


Predicted and documented in Rybakov et al., 2005 sinkhole collapse in the Assael mud flat were confirmed there later (Rybakov et al., 2006).

Mechanism of sinkhole generation
from (Abelson, 2005)

1. Hydrological factor

There is a hydrological connection between the Dead Sea and freshwater levels.
Dead Sea decline is responsible for freshwater decrease.

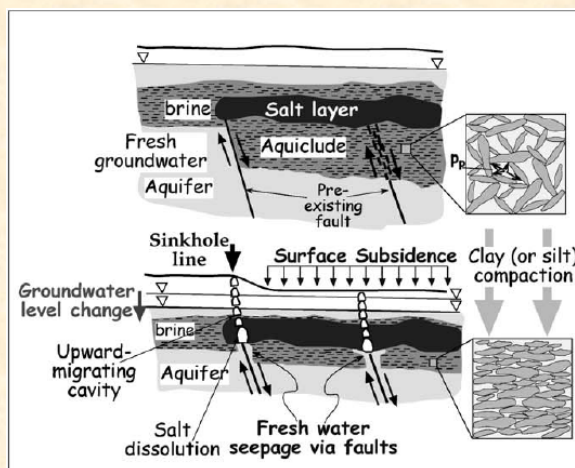


a. Eastward migration of sub-saturated groundwater

The primary cause of sinkhole formation is dissolution of the salt layer by groundwater.

2. Effect—The Role of Land Subsidence and Faults

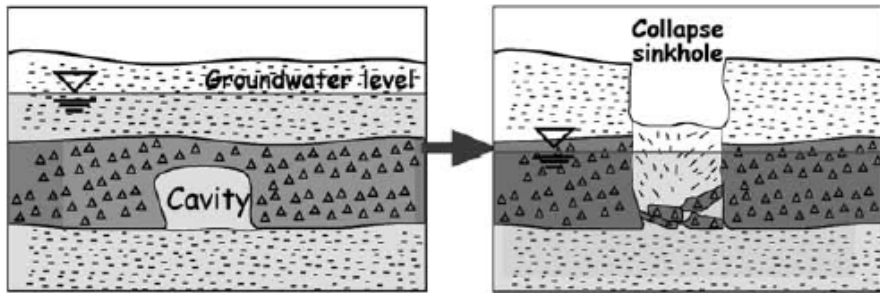
The decline of the Dead Sea level increases the effective stress and generates differential compaction of the aquiclude layers. The differential compaction results in shear deformation of the aquiclude layers, confining the salt layer along pre-existing faults.



b. Differential compaction of aquitard layers and breaching of faults

3 Destabilization of cavities

The increase in effective stress due to the Dead Sea level drop also directly destabilizes cavities in the salt layer, promoting the collapse of overlying sediments. This effect serves as a catalyst for sinkhole collapse rather than causing new underground cavities. (Abelson, 2005)

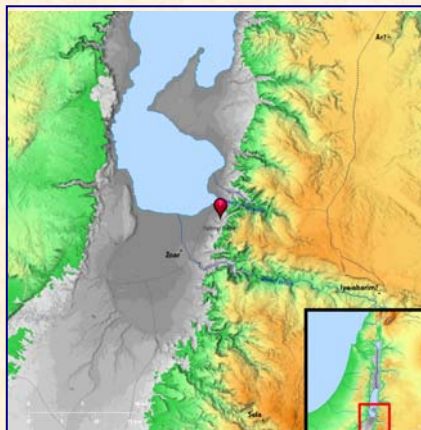


c. Destabilization of cavities:
Decrease of groundwater level → Increase of effective stress

Was the sinkhole phenomenon encountered in the past?

"And the vale of Siddim was full of slimepits;
and the kings of Sodom and Gomorrah fled,
and fell there; and they that remained fled to the
mountain."

(Genesis, Abram and Lot part: 14-10)



Valley of Siddim
and the
surrounding region
(from Biblos.com)

RESULTS

The formation of sinkholes is attributed to the dissolution of subsurface salt layer by fresh groundwater due to the drop Dead Sea and associated groundwater level.

Appearance of sinkholes started in the yearly 1980s when the Dead Sea level was about -400 regarding Israeli leveling system.

Human activity seriously affected on the Dead Sea ecosystem. From other hand, there are evidences (Frumkin, 2002; Bookman-KenTor et al., 2004) that Dead Sea level like in the modern period and even lower encounter during the last several thousands years.

**Nowadays, some effectively technique
were developed to understand better
sinkholes generation and even to
predict their appearance.
One such technique is micromagnetic
method cave detection near Dead Sea.**

Acknowledgments

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photograph division for help in the data base
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Thank you